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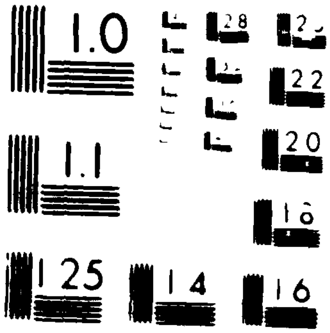
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RAPID SEARCH FOR SPHERICAL OBJECTS IN AERIAL PHOTOGRAPHS

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TECHNICAL REPORT

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RAPID SEARCH FOR SPHERICAL OBJECTS IN AERIAL PHOTOGRAPHS

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July 1986

Rapid Search for Spherical Objects
in Aerial Photographs

Kenneth Cox
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ABSTRACT

This paper describes a method for detecting and segmenting spherical features using the gradient angle transform. An analysis of the gradient angle for ideal spheres is presented, with a discussion of how this may be used to locate the boundaries of the sphere. The algorithms used by a program which detects and segments spherical features are then presented. The results of applying the program to images with naturally-occurring spherical features are given.

Acknowledgements: This work was supported in part by the Defense Mapping Agency under contract DMA800-85-C-0010.

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1. INTRODUCTION

One of the goals of computer vision research is the development of software systems for the analysis of aerial photographs. One aspect of this analysis is the detection and segmentation of various features, where detection refers to identifying the presence of a feature and segmentation refers to locating the boundaries of the feature. The information produced by these programs may be used both to develop a high-level interpretation of the image and as entries in a feature database.

Previous researchers have developed detector/segmenters for such features as roads, rivers, and buildings. These detectors have largely relied on image edges and image grey levels both to detect and to segment the features [1,2,5,10].

We have developed a detector/segmenter for spherical features which uses the direction of the image gradient for segmentation. This value, here called the *gradient angle*, indicates the direction of greatest change in image intensity. Approximations to the gradient angle have previously been used in certain special transforms (for example, the Hough transform for locating circles). The detector/segmenter presented here uses continuity of the gradient angle in segmentation, an approach which is to the best of our knowledge original.

We feel that the detector/segmenter will form a useful part of a photo analysis system. We also believe that the angle-based segmentation methods will prove important for other types of features.

Section 2 of this report describes the gradient angle and explains how it can be used for segmentation. The section concludes with an analysis of the gradient angle for ideal spheres under point-source illumination. Section 3 outlines the algorithms used in the sphere detector/segmenter program. Section 4 gives the results of applying the program to both synthetically-generated and actual spherical surfaces. Our conclusions are presented in section 5.

2. GRADIENT

2.1. Definitions

The *gradient* of a point in an image is a measure of the change in the image intensity at that point. The most common use of the gradient is as an edge detector; points of high gradient mark edges between two regions. Many edge-detecting gradient measures have been described, including the Sobel, Kirsch, Prager, and Marr-Hildreth detectors; most of these can be calculated using a convolution [1,3,6,7,9,11].

Define the quantities GX and GY as the gradient in the X and Y directions for a particular point, computable by any of several convolutions; for example, the convolution masks

$$\text{GX} \quad \begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix} \qquad\qquad \text{GY} \quad \begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{matrix}$$

produce satisfactory results. Using these, the *gradient magnitude* GM and *gradient angle* GA are computed by the formulas:

$$GM = \mathrm{sqrt}(GX^2 + GY^2)$$

$$GA = \tan^{-1}(GY/GX)$$

The results presented in this paper use the above operations; however, these are computationally expensive. We have found that approximating GM as the sum of the absolute values of GX and GY, and GA by a table look-up is usually satisfactory.

2.2. Use in Segmentation

The gradient angle has proved to be useful for certain types of segmentation, including uses reported in [4]. The value of the gradient angle is the direction of greatest change in pixel intensity. Thus, a region of smoothly increasing intensity, such as is often found in curved objects, has approximately constant gradient angle. Conversely, a region of approximately constant intensity has irregular, highly textured gradient angle due to slight variations in intensity. This makes the gradient angle of an image an excellent space to search for curved features, since the desired features form large regions of slowly-varying value while planar features are broken up. Such curved features are among the more difficult to detect using traditional segmentation algorithms.

2.3. Special Analysis of Sphere

Consider the gradient angle transform of a spherical surface of radius R illuminated by a distant point-source. Using a simple reflectance model as in [1], the intensity of a point on the surface is proportional to the cosine of the angle between the light source and the surface normal.

Using a coordinate system centered on the sphere, let the light source be ϕ degrees above the X-Y plane and ψ degrees from the X-axis. Let the viewer be located on the Z-axis. Define three constants C1, C2, C3 as

$$C1 = \cos(\phi) * \cos(\psi)$$

$$C2 = \cos(\phi) * \sin(\psi)$$

$$C3 = \sin(\psi)$$

The gradient angle function GA(x,y,z) (where $x^2 + y^2 + z^2 = R^2$) for a point on the sphere illuminated by the light source is

$$GA(x,y,z) = \tan^{-1}((C2-C3(y/z))/(C1-C3(x/z)))$$

Note that for the light source directly overhead ($\phi = 90$),

$$GA(x,y,z) = \tan^{-1}(y/x)$$

The gradient angle transform of a sphere can be used to determine the approximate location (ϕ and ψ) of the light source. A histogram of the gradient angle over the sphere has a maximum at a position corresponding to the angle ψ, while the difference between the maximum and minimum is inversely related to ϕ. This relation has proved to hold adequately for actual spheres and is used for parameter extraction in the sphere detector.

One significant difference between the ideal reflective behavior described above and that of actual spheres is ***specular reflection***. This is a brighter area on the sphere in the region where the surface normal bisects the angle between the observer and the light source. The image of the sphere can thus be divided into regions of shadow, matte-reflectivity, and specular-reflectivity; the boundaries between these areas can be determined from a histogram of the sample sphere.

Figure 1(a) is a group of synthetically-generated spheres. The direction of the light source (ϕ) varies across the rows, while the height of the light source (ψ) decreases down the columns. Figure 1(b) is the gradient angle transform of the image.

Figure 2 is a series of histograms of the gradient angle transform of a synthetic sphere as the angle ϕ varies. Note that the location of the histogram peak (taking averaged values and ignoring the spikes) is related to ϕ. Since the histogram values run from 0 to 255, to get the degree value corresponding to any point multiply that value by 360/255. We have found that ϕ can be determined to within 15 degrees using the histogram peak.

3. SPHERE DETECTION AND SEGMENTATION

The sphere detector and segmenter requires as input the following:

- the image to be examined
- the gradient angle transform of the image
- a sample feature
- (optional) points of possible detected spheres

The first step in the processing is parameter-extraction. The program examines the sample feature to determine the approximate position of the sun, the cutoffs between various intensities on the sphere, and similar parameters.

The next step is feature detection, which is done in one of two ways. If some other program (such as a correlation algorithm) has already been used for feature detection, the program uses its results as possible features. Otherwise, the program performs a simple pattern search of the image to detect possible features.

The third step is the segmentation-validation loop. Within this loop, the program selects a possible feature and uses angle-based segmentation to create a candidate region. This region is processed for parameters, which are compared to those of the sample feature. The region is then classified as POSITIVE or NEGATIVE and stored. The segmentation-validation loop repeats until all detected features are classified.

3.1. Parameter Extraction

The parameter-extraction step of processing uses the sample feature to compute statistical information about the sphere. This information is used in both the feature detection and feature validation steps.

The area, perimeter, X and Y centroids, and radius of the given feature are first extracted. Histograms of the original image and the gradient angle transform over the feature region are then computed. The histogram bins each contain four (consecutive) grey levels; since the images we use have 256 grey levels (8-bits), each histogram has 64 bins. Each histogram entry is replaced by the average of the entry and its neighbors: this smooths the histogram and aids in the parameter extraction

The maximum of the gradient angle histogram is located and used to determine the approximate direction of the sun, as described in section 2.3. This value is then displayed and the user is allowed to change it if desired. The original image histogram is examined to determine approximate thresholds between the shadowed, matte-reflecting, and specular-reflecting areas of the sphere. The shadowed area is taken to run from 0 to the first local minimum as the histogram index increases, while the specular-reflecting area is taken to run from 255 to the first local minimum as the histogram index decreases. After these are computed the user is allowed to change the values if desired.

Parameters for a "pattern-search" of the image are then computed. Consider a sphere thresholded to three levels corresponding to the shadowed, matte-reflecting, and specular-reflecting regions. Moving along a line through the center of the sphere in the direction away from the light source, these three regions will be encountered in the order "specular, matte, shadow" (i.e., a consecutive series of points on the line consisting of one or more specular points, one or more matte points, and one or more shadow points). We use this both to extract the parameters and to detect spheres.

Lines parallel to the direction of the sun are drawn across the sample feature. Each line is examined for the pattern "specular, matte, shadow". The widths of the three regions are stored. After the whole of the sample feature has been so processed, the stored data is evaluated to obtain minimum and maximum lengths for each of the three regions as well as bounds on the ratios of the lengths.

3.2. Detection

If another program has been used to locate possible spheres, these results are used. We have had great success with a correlation (using sum of squared differences) of the sample feature in the gradient angle space against the whole image. This has proved very effective in detecting spheres in that it both detects all spheres of approximately the same size as the feature and makes very few false detections.

If no such program has been used, a pattern-search is performed to detect spheres. The parameters previously computed are used.

Scans of the image at the sun angle plus 15 degrees and the sun angle minus 15 degrees are made. When the pattern "specular matte shadow" is encountered with the lengths and length ratios of the three regions falling within the parameters previously determined, the points making up the pattern are marked POSSIBLE. Points marked by both scans which are also in the specular range are taken as *candidate points*.

3.3. Segmentation

In the segmentation step, the brightest remaining candidate point is selected as the initial point. A region-grower based on image intensity is first used. Using standard methods of adding points to the region if they meet the selection criteria, this grower produces a region around the candidate point for which the image intensity falls within the specular range.

The second region grower, based on gradient angle continuity, is then used to expand the region. Points on the perimeter of the region which border at least three points already in the region are considered. If the minimum and maximum gradient angle of the bordering points differ by less than 60 degrees and the gradient angle of the point under consideration lies in the range [minangle-15 .. maxangle+15], the point is added to the region. Otherwise the point is marked as unusable. This process is continued until no more points can be added to the region. The values 60 degrees and 15 degrees used above were established through experimentation.

3.4. Validation

The region created by the segmentation step is processed for the same statistics as in the parameter-extraction step. The region is then "graded" by applying a number of tests designed to evaluate its sphericity. If the region fails too many of these tests, it receives a NEGATIVE evaluation; otherwise it receives a POSITIVE evaluation.

The region is then displayed to allow the user to change the evaluation if desired. Regions with a final evaluation of POSITIVE are saved, and any candidate points within or bordering the region are removed from further consideration. The latter step is to avoid duplication of regions.

The validation tests include the following:

- -- check that the ratio of the area (points within region) and perimeter (points bordering region) are consistent with that of a sphere

- -- check that the angle of the sun computed from the region agrees with the actual angle

- -- check that the shadow, matte, and specular thresholds agree with those of the original feature

- -- check that the percentage areas of shadow, matte, and specular zones agree with those of the original feature

Segmentation and validation take place together within a loop; points are selected, regions segmented, and validation checks made until no further candidate points remain.

4. RESULTS

Figures 3 through 6 show the results of a program run. Figure 3 shows the initial image, from which spheres are to be extracted. This image was first processed to get the gradient angle transform, and a sample feature (the sphere toward the upper left) was extracted.

Figure 4 shows the results of a correlation detector. The sample feature's gradient angle was correlated over the whole image, using a squared-differences computation. Points of low intensity correspond to good correlation; in the figure, these appear in red. We were able to use a simple correlator on the spheres because they remain unchanged if rotated. More sophisticated methods are required for non-symmetric objects.

Figure shows the results of detection by pattern match as produced by the program. Figure 5(a) shows the actual pattern produced as described earlier, while figure 5(b) shows the detected points. The program used these detected points in its search.

Figure 6 depicts the areas which the program classified as spheres, highlighted in red. Note that all spheres have been detected, and that no false positive classifications have been made.

5. CONCLUSIONS

The motivation for this work rests with the need for developing algorithms which detect and segment specific types of objects in aerial photographs. When both the number and size of the photographs are large this task becomes increasingly difficult to be performed by humans, who get tired and lose concentration.

Our algorithm is specialized for seeking out spherical objects having smooth reflecting surfaces. It requires a sample object whose analysis is used to compute var parameters involved in the detection and validation process. All parameters are subject to human review and correction, if necessary.

The principal means of detection is the continuous nature of the gradient angle. There are strong indications that a similar approach may be useful for many other important aerial features. Although the continuity of the gradient angle seems to be an important, physically relevant characteristic, it has received only limited attention in the past.

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Figure 1(a). Synthetically generated spheres; the direction of the light source ϕ varies across the rows, while the height of the light source ψ decreases down the columns

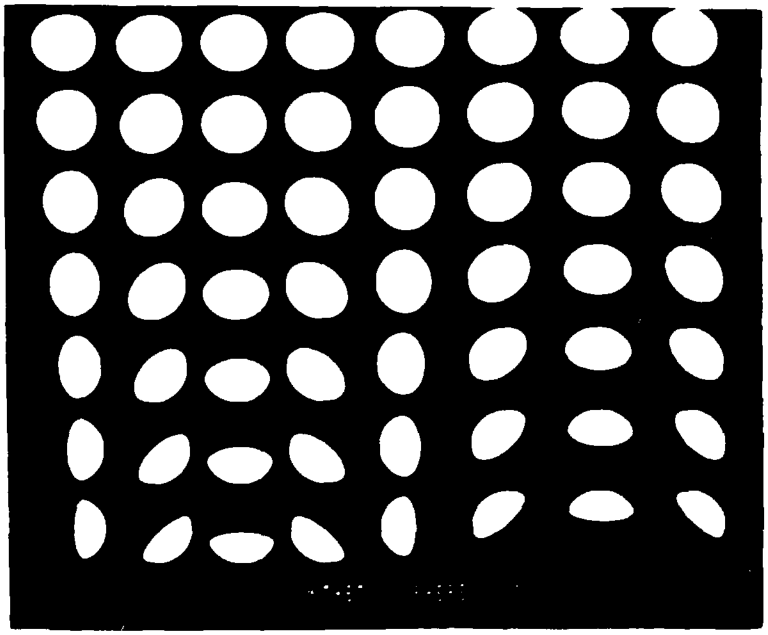


Figure 1(b). The gradient angle transform of the spheres in Figure 1(a).

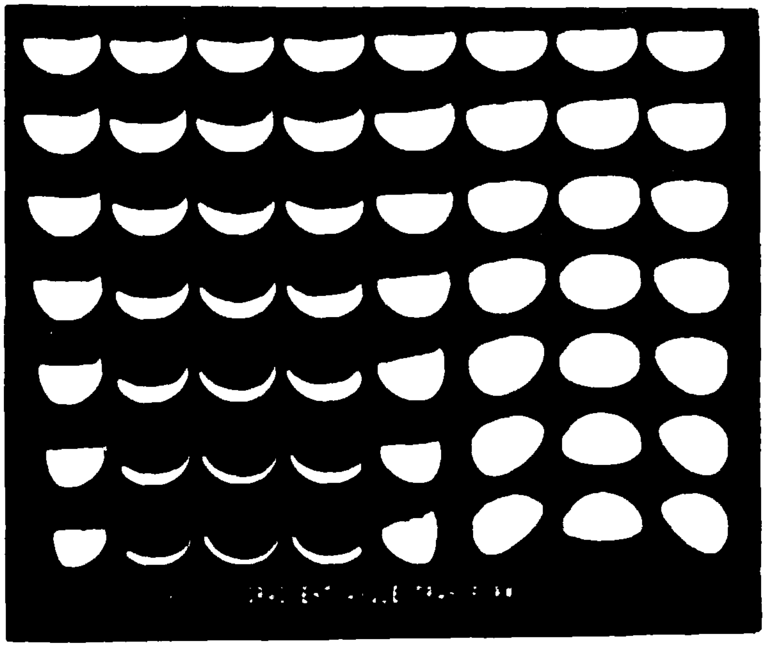
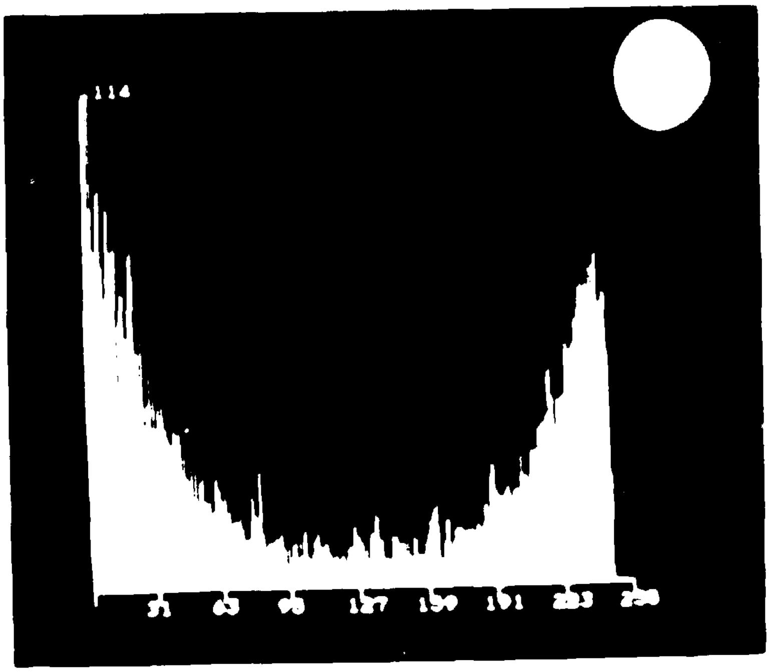
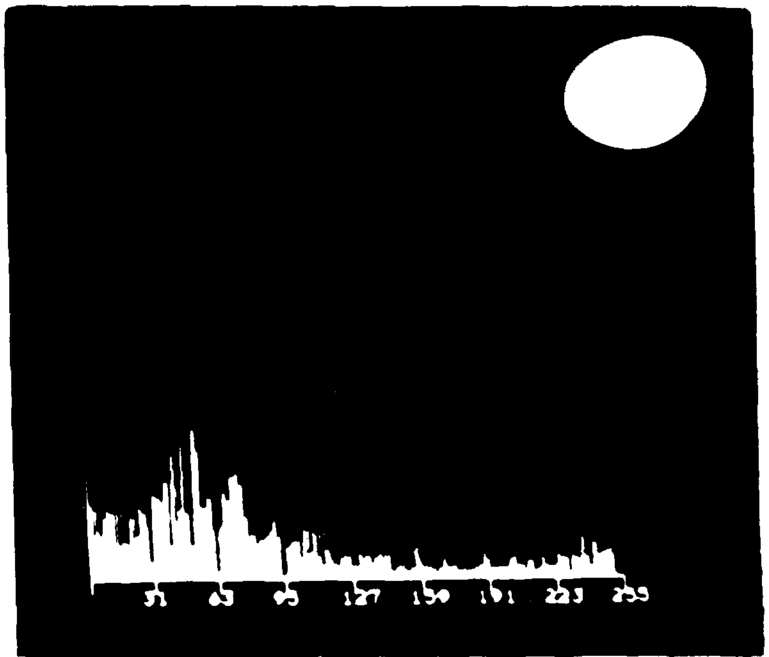


Figure 2(a). A synthetically generated sphere with ϕ = [illegible] degrees and the histogram of the gradient angle transform.





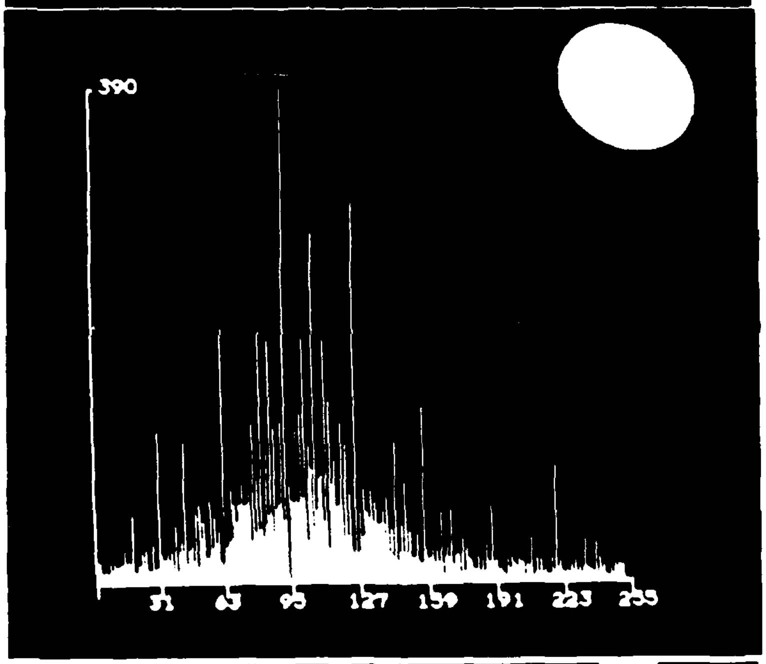


Figure 2(c). $\phi = 144$ degrees, or 2/5 of the total circle.

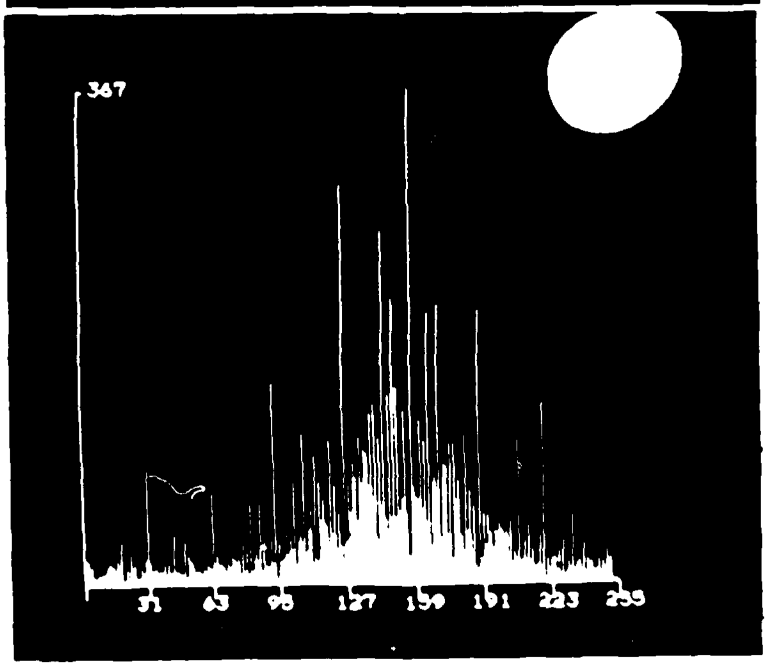
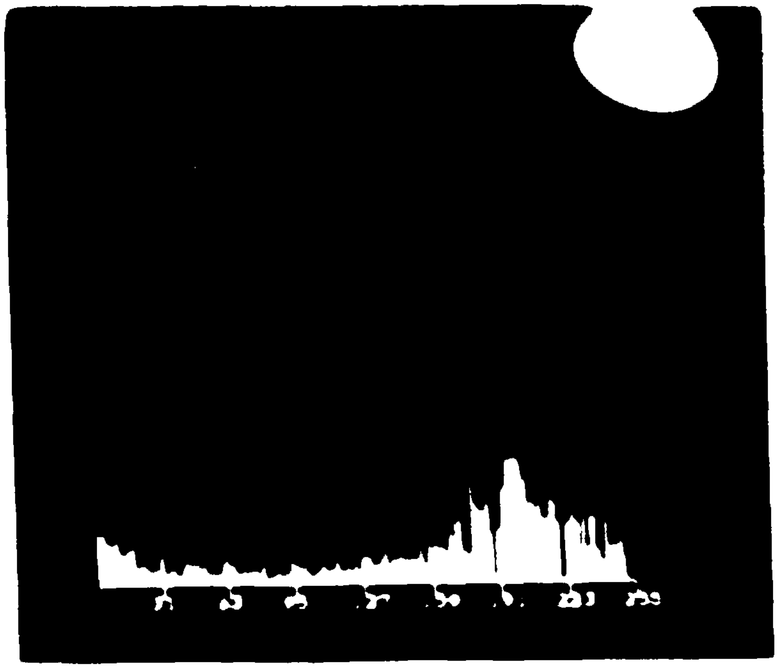


Figure 2(d). $\phi = 216$ degrees, or 3/5 of the total circle.



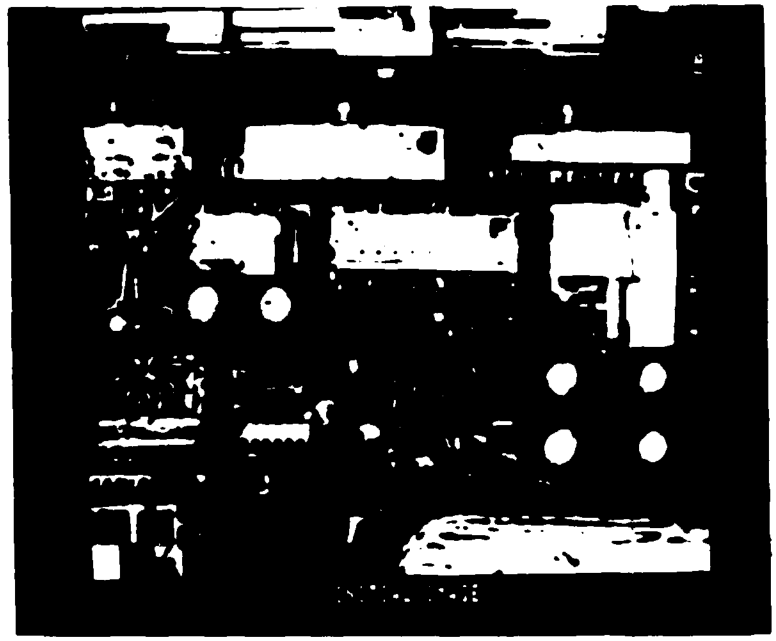


Figure 3. Initial image containing spherical features (storage tanks)

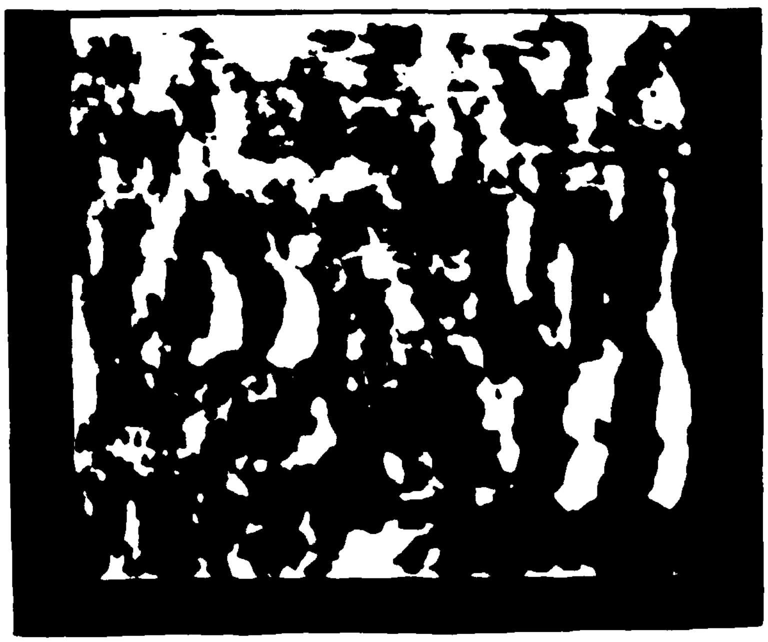


Figure 4. Results of correlating one of the spheres against the whole image.

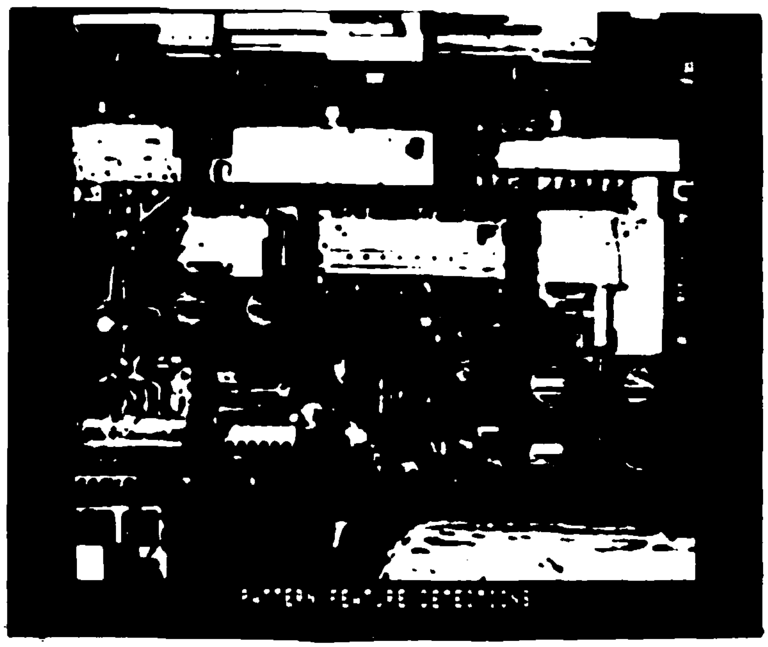


Figure 5(b). Points detected by pattern search (marked in both search directions and high-intensity).

Figure 6. Detected spherical features

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